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(54) **AUXILIARY FEEDWATER VALVE CONTROL APPARATUS OF STEAM GENERATOR**

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F22B 35/00	(2006.01)
F22B 37/46	(2006.01)

(52) **U.S. Cl.**

CPC ***G21C 7/32*** (2013.01); ***F22B 35/004*** (2013.01); ***F22B 37/46*** (2013.01); *G21C 15/182* (2013.01)

(58) **Field of Classification Search**

USPC 376/297

See application file for complete search history.

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(57) **ABSTRACT**

An auxiliary feedwater valve control apparatus of a steam generator that operates an auxiliary feedwater valve in an auxiliary feed water system provided as a protective system of a main feed water system that feeds secondary cooling water to a steam generator, includes a water-level detection means that detects a water level of secondary cooling water in the steam generator, a water-level-deviation calculation means that calculates a deviation between a preset target water level and a water level detected by the water-level detection means, a valve-operation setting means that sets an aperture of the auxiliary feedwater valve corresponding to a deviation of the water level, and a valve drive means that outputs a signal for driving the auxiliary feedwater valve corresponding to setting by the valve-operation setting means.

5 Claims, 4 Drawing Sheets

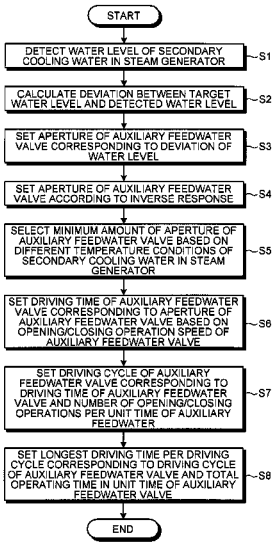

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FIG.1

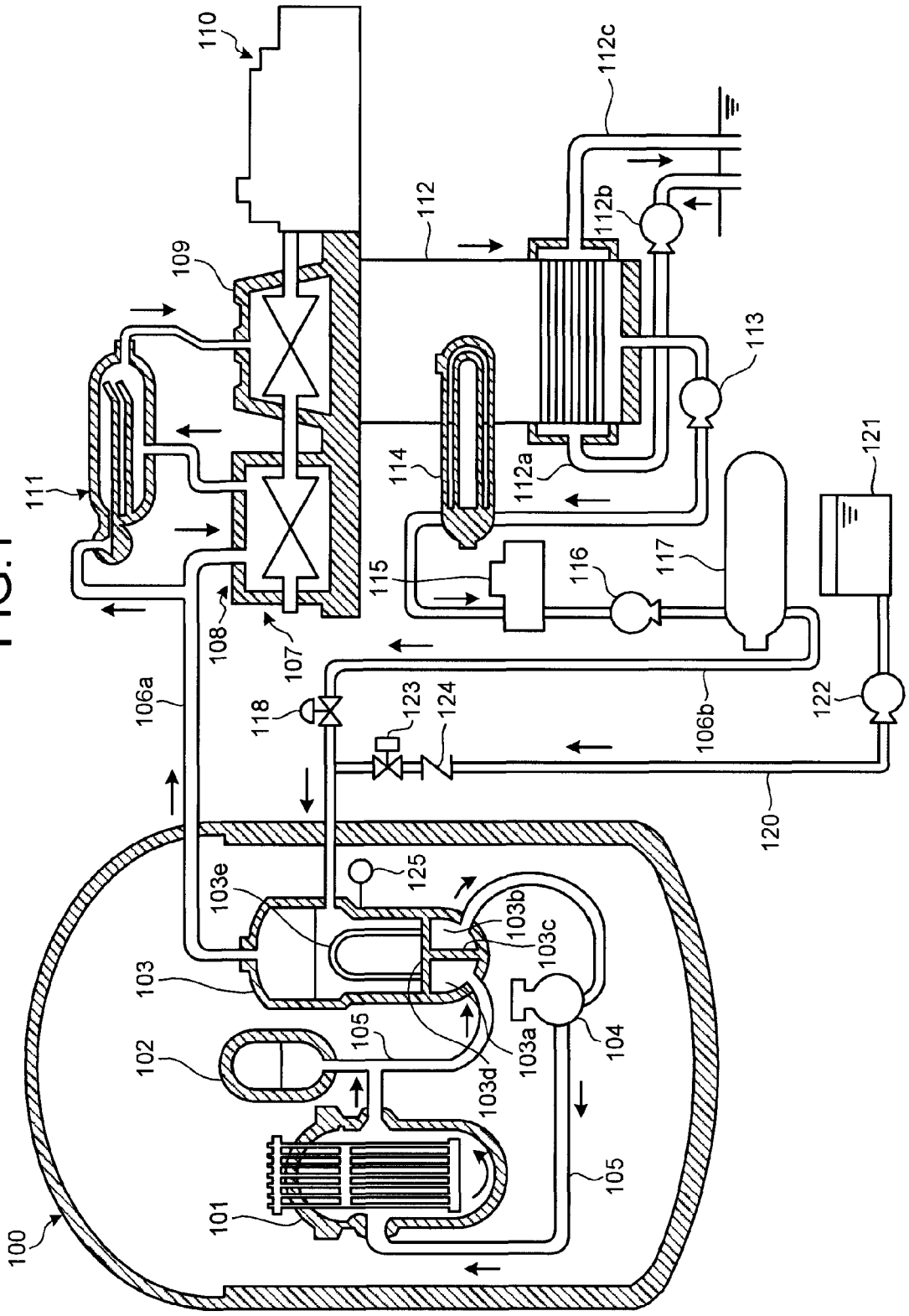

110
112c
112
112b
109
113
111
114
112a
121
115
116
117
108
107
106a
118
123
124
106b
122
120
125
103e
103b
103c
103
105
102
103a
104
103d
105
101
100

FIG.2

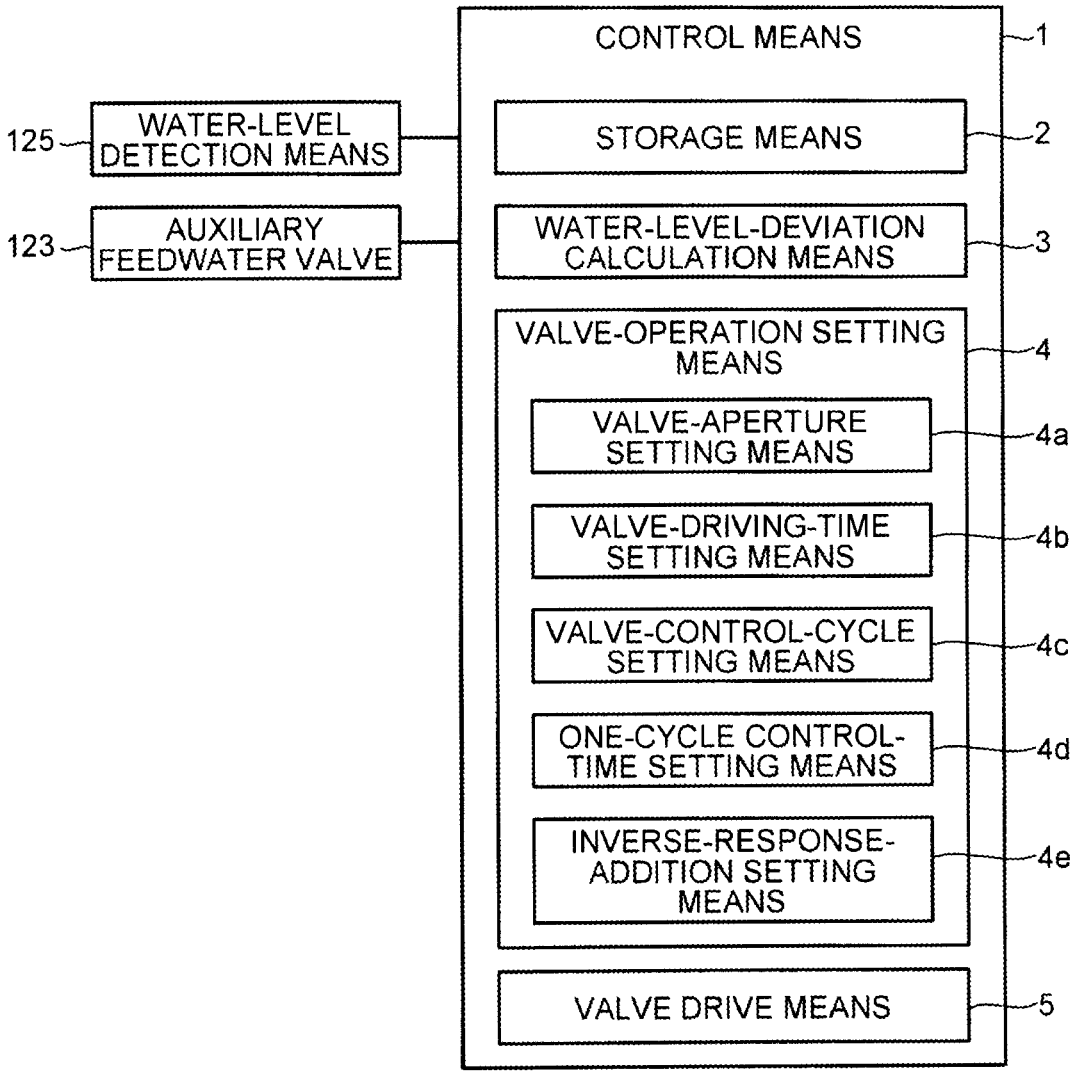

CONTROL MEANS
1
125
WATER-LEVEL DETECTION MEANS
123
AUXILIARY FEEDWATER VALVE
STORAGE MEANS
2
WATER-LEVEL-DEVIATION CALCULATION MEANS
3
VALVE-OPERATION SETTING MEANS
4
VALVE-APERTURE SETTING MEANS
4a
VALVE-DRIVING-TIME SETTING MEANS
4b
VALVE-CONTROL-CYCLE SETTING MEANS
4c
ONE-CYCLE CONTROL-TIME SETTING MEANS
4d
INVERSE-RESPONSE-ADDITION SETTING MEANS
4e
VALVE DRIVE MEANS
5

FIG.3

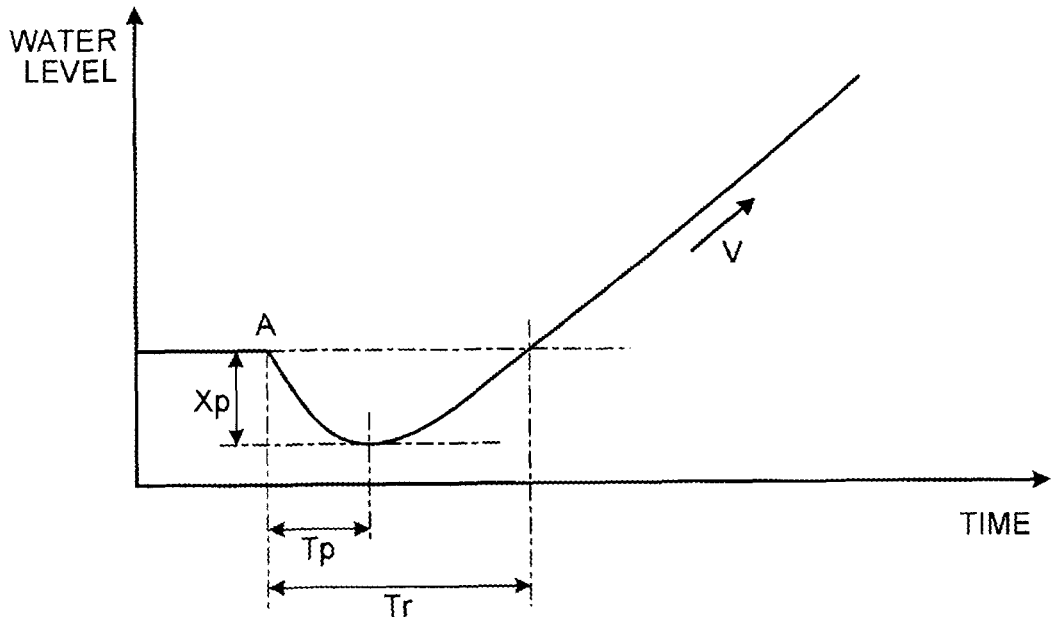
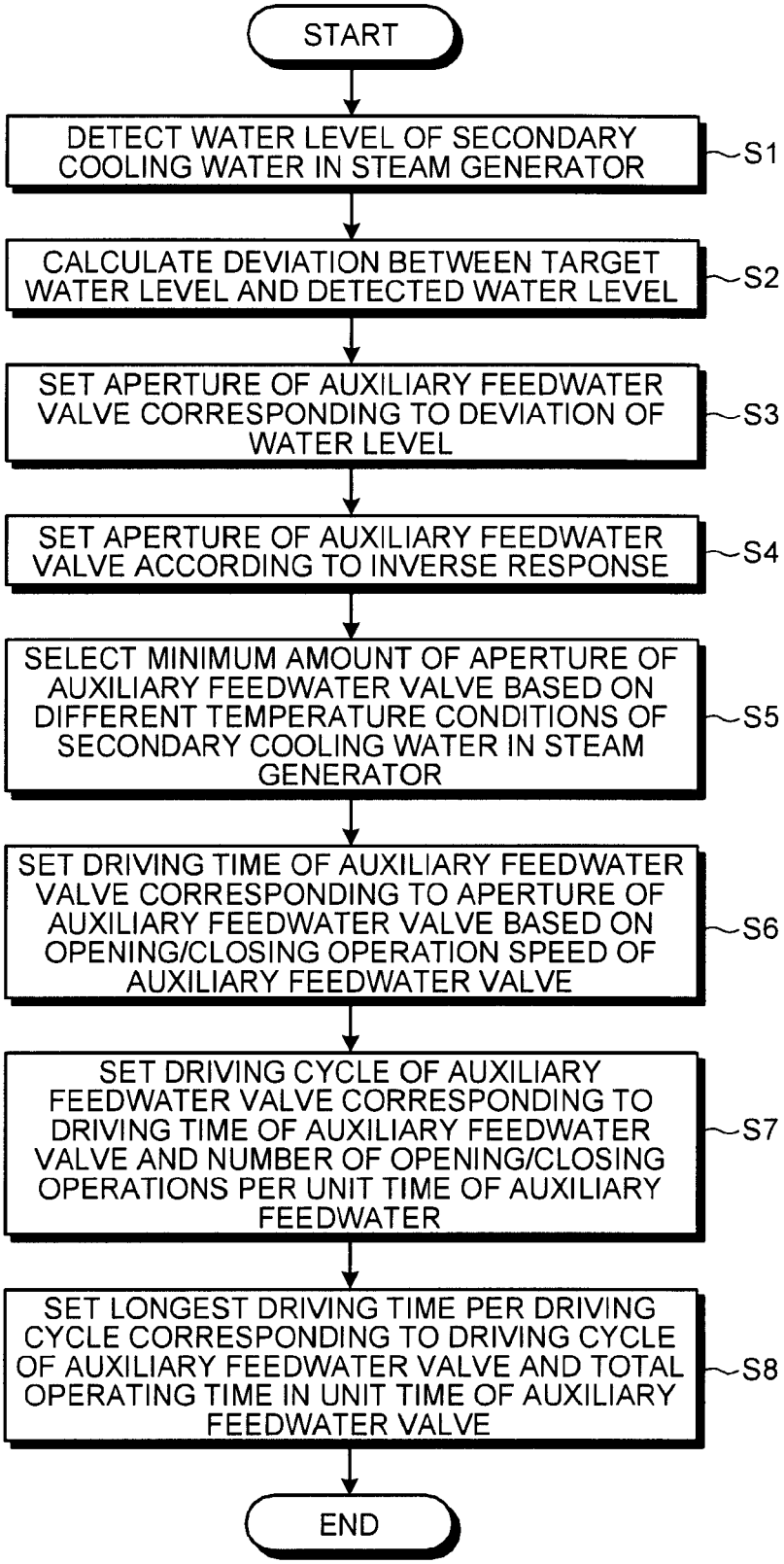


FIG.4


START
DETECT WATER LEVEL OF SECONDARY COOLING WATER IN STEAM GENERATOR
S1
CALCULATE DEVIATION BETWEEN TARGET WATER LEVEL AND DETECTED WATER LEVEL
S2
SET APERTURE OF AUXILIARY FEEDWATER VALVE CORRESPONDING TO DEVIATION OF WATER LEVEL
S3
SET APERTURE OF AUXILIARY FEEDWATER VALVE ACCORDING TO INVERSE RESPONSE
S4
SELECT MINIMUM AMOUNT OF APERTURE OF AUXILIARY FEEDWATER VALVE BASED ON DIFFERENT TEMPERATURE CONDITIONS OF SECONDARY COOLING WATER IN STEAM GENERATOR
S5
SET DRIVING TIME OF AUXILIARY FEEDWATER VALVE CORRESPONDING TO APERTURE OF AUXILIARY FEEDWATER VALVE BASED ON OPENING/CLOSING OPERATION SPEED OF AUXILIARY FEEDWATER VALVE
S6
SET DRIVING CYCLE OF AUXILIARY FEEDWATER VALVE CORRESPONDING TO DRIVING TIME OF AUXILIARY FEEDWATER VALVE AND NUMBER OF OPENING/CLOSING OPERATIONS PER UNIT TIME OF AUXILIARY FEEDWATER
S7
SET LONGEST DRIVING TIME PER DRIVING CYCLE CORRESPONDING TO DRIVING CYCLE OF AUXILIARY FEEDWATER VALVE AND TOTAL OPERATING TIME IN UNIT TIME OF AUXILIARY FEEDWATER VALVE
S8
END

AUXILIARY FEEDWATER VALVE CONTROL APPARATUS OF STEAM GENERATOR

FIELD

The present invention relates to an auxiliary feed water system provided as a protective system of a main feed water system that feeds secondary cooling water to a steam generator in a pressurized water reactor (PWR), and relates to an auxiliary feedwater valve control apparatus of a steam generator that controls a flow rate of feed water by operating an auxiliary feedwater valve in the auxiliary feed water system.

BACKGROUND

Conventionally, in a method of controlling a flow rate of feed water to a steam generator described in Patent document 1, a main feed water system controlled according to a program is provided to maintain a water level of secondary cooling water in the steam generator. The main feed water system is backed up by an auxiliary feed water system and is automatically switched to the auxiliary feed water system when the main feed water system cannot maintain a minimum water level.

CITATION LIST

Patent Literature

[Patent Document 1] Japanese Patent Application Laid-open No. S63-96405

SUMMARY

Technical Problem

However, as described in Japanese Patent Application Laid-open No. S63-96405, the auxiliary feed water system is a protective system including only a minimum control device, and does not automatically adjust a flow rate of feed water to the steam generator to maintain the water level according to a programmed procedure. The protective system including only a minimum control device means that, in control of an auxiliary feedwater valve, only an opening/closing signal is output, and only when an opening signal is ON, control is performed in an opening direction at a predetermined speed, and only when a closing signal is ON, control is performed in a closing direction at a predetermined speed. Therefore, it does not execute any feedback control on an aperture of the auxiliary feedwater valve corresponding to the water level.

Therefore, the auxiliary feedwater valve is operated by a manual operation of an operator to control so that the water level of the steam generator falls within a certain variation range. The water level control of the steam generator by the auxiliary feedwater valve is performed in a plant output state when a plant is shut down at the time of an accident. Therefore, operations of other devices and monitoring of measuring gauges need to be performed frequently at the same time, and thus there is a large burden on the operator. Accordingly, there has been a demand for automatic water level control of a steam generator by an auxiliary feedwater valve.

The present invention has been achieved in order to solve the above problems, and an object of the present invention is to provide an auxiliary feedwater valve control apparatus of a steam generator that can automatically control a water level by an auxiliary feedwater valve in an auxiliary feed water system.

Solution to Problem

According to an aspect of the present invention, an auxiliary feedwater valve control apparatus of a steam generator that operates an auxiliary feedwater valve in an auxiliary feed water system provided as a protective system of a main feed water system that feeds secondary cooling water to a steam generator, includes: a water-level detection unit that detects a water level of secondary cooling water in the steam generator; a water-level-deviation calculation unit that calculates a deviation between a preset target water level and a water level detected by the water-level detection unit; a valve-operation setting unit that sets an aperture of the auxiliary feedwater valve corresponding to a deviation of the water level; and a valve drive unit that outputs a signal for driving the auxiliary feedwater valve corresponding to setting by the valve-operation setting unit.

According to the auxiliary feedwater valve control apparatus of a steam generator, the auxiliary feedwater valve can be operated to perform water level control of secondary cooling water in the steam generator automatically without depending on operations by an operator.

Advantageously, in the auxiliary feedwater valve control apparatus of a steam generator, the valve-operation setting unit sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance.

According to the auxiliary feedwater valve control apparatus of a steam generator, the driving time of the auxiliary feedwater valve for realizing the set aperture of the auxiliary feedwater valve is set based on the opening/closing operation speed of the auxiliary feedwater valve. Accordingly, the aperture of the auxiliary feedwater valve can be controlled corresponding to the performance of the auxiliary feedwater valve.

Advantageously, in the auxiliary feedwater valve control apparatus of a steam generator, number of opening/closing operations per unit time of the auxiliary feedwater valve is defined, and the valve-operation setting unit sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance, and sets a driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary feedwater valve.

According to the auxiliary feedwater valve control apparatus of a steam generator, for example, when the set driving time of the auxiliary feedwater valve is relatively short (when a deviation between the target water level and the detected water level is relatively small), the driving cycle of the auxiliary feedwater valve is set long (the number of times of driving is reduced). With this configuration, the water level can be controlled to reach the target water level more quickly. On the other hand, when the set driving time of the auxiliary feedwater valve is relatively long (when the deviation between the target water level and the detected water level is relatively large), the driving cycle of the auxiliary feedwater valve is set short (the number of times of driving is increased). With this configuration, the water level can be controlled to reach the target water level, while stabilizing the water level by finely adjusting the aperture. By setting the driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary

feedwater valve in this manner, appropriate water level control can be performed until the water level reaches the target water level.

Advantageously, in the auxiliary feedwater valve control apparatus of a steam generator, number of opening/closing operations per unit time and a total operating time in a unit time of the auxiliary feedwater valve are defined, and the valve-operation setting unit sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance, and sets a driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary feedwater valve, and sets a longest driving time per driving cycle corresponding to the set driving cycle of the auxiliary feedwater valve and the total operating time in the unit time of the auxiliary feedwater valve.

According to the auxiliary feedwater valve control apparatus of a steam generator, for example, when the set driving time of the auxiliary feedwater valve is relatively short (when a deviation between the target water level and the detected water level is relatively small), the driving cycle of the auxiliary feedwater valve is set long (the number of times of driving is reduced) and the longest driving time per driving cycle is set relatively long. With this configuration, the water level can be controlled to reach the target water level more quickly. On the other hand, when the set driving time of the auxiliary feedwater valve is relatively long (when the deviation between the target water level and the detected water level is relatively large), the driving cycle of the auxiliary feedwater valve is set short (the number of times of driving is increased) and the longest driving time per driving cycle is set relatively short. With this configuration, the water level can be controlled to reach the target water level, while stabilizing the water level by finely adjusting the aperture. By setting the driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary feedwater valve in this manner, and by setting the longest driving time per driving cycle corresponding to the total operating time in the unit time of the auxiliary feedwater valve, appropriate water level control can be performed until the water level reaches the target water level.

Advantageously, in the auxiliary feedwater valve control apparatus of a steam generator, the valve-operation setting unit acquires water-level time-response information corresponding to an aperture of the auxiliary feedwater valve in advance, determines a parameter in a non-minimum phase transfer function, which approximates a response to the water level by an inverse response from a set aperture of the auxiliary feedwater valve, based on the water-level time-response information, and sets the aperture of the auxiliary feedwater valve, taking into consideration a gain margin and a phase margin of frequency characteristics of the non-minimum phase transfer function in which the parameter has been determined.

According to the auxiliary feedwater valve control apparatus of a steam generator, water level variation at the time of an inverse response can be suppressed by setting the aperture of the auxiliary feedwater valve according to the inverse response.

Advantageously, in the auxiliary feedwater valve control apparatus of a steam generator, the valve-operation setting unit obtains an aperture of the auxiliary feedwater valve, respectively, under different temperature conditions of secondary cooling water in the steam generator included in the water-level time-response information, and selects a minimum value thereof.

When a temperature of secondary cooling water in the steam generator is high, a temperature difference from auxiliary cooling water is large and a maximum inverse response amount increases, and if a feed amount of auxiliary cooling water is large, the maximum inverse response amount further increases. Therefore, according to the auxiliary feedwater valve control apparatus of a steam generator, by setting the aperture of the auxiliary feedwater valve according to an inverse response accompanied by a temperature condition to the minimum amount, water level variation at the time of the inverse response can be suppressed even if there is a large temperature difference.

Advantageous Effects of Invention

According to the present invention, it is possible to automatically control a water level by an auxiliary feedwater valve in an auxiliary feed water system.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic configuration diagram of an example of a nuclear power plant.

FIG. **2** is a block diagram of an auxiliary feedwater valve control apparatus according to an embodiment of the present invention.

FIG. **3** is a conceptual diagram of an inverse response.

FIG. **4** is a flowchart of an operation of the auxiliary feedwater valve control apparatus.

DESCRIPTION OF EMBODIMENTS

Exemplary embodiments of the present invention will be explained below in detail with reference to the accompanying drawings. The present invention is not limited to the embodiments. In addition, constituent elements in the following embodiment include those that can be replaced by and easily occur to persons skilled in the art, or that are substantially equivalent.

FIG. **1** is a schematic configuration diagram of a nuclear power plant. As shown in FIG. **1**, in a containment **100** of a nuclear power plant, a pressurized water reactor (PWR) **101**, a pressurizer **102**, a steam generator **103**, and a primary cooling water pump **104** are sequentially connected by a primary cooling water pipe **105**, thereby constituting a circulation path of primary cooling water.

In the steam generator **103**, an inlet-side water chamber **103***a* and an outlet-side water chamber **103***b* are provided and divided by a partition plate **103***c* in a lower part thereof formed in a hemispherical shape. The inlet-side water chamber **103***a* and the outlet-side water chamber **103***b* are divided from an upper side of the steam generator **103** by a tube plate **103***d* provided on the ceiling of the inlet-side water chamber **103***a* and the outlet-side water chamber **103***b*. Heat transfer tubes **103***e* having an inverted U-shape are provided on the upper part of the steam generator **103**. Ends of the heat transfer tubes **103***e* are supported by the tube plate **103***d* to connect the inlet-side water chamber **103***a* and the outlet-side water chamber **103***b*. The primary cooling water pipe **105** on an inlet side is connected to the inlet-side water chamber **103***a*, and the primary cooling water pipe **105** on an outlet side is connected to the outlet-side water chamber **103***b*. A secondary cooling water pipe **106***a* on an outlet side is connected to an upper end on the upper side of the steam generator **103**

divided by the tube plate **103***d*, and a secondary cooling water pipe **106***b* on an inlet side is connected to the side of the steam generator **103** on the upper side.

In the nuclear power plant, the steam generator **103** is connected to a steam turbine **107** outside of the containment **100** via the secondary cooling water pipes **106***a* and **106***b*, thereby constituting a circulation path of secondary cooling water.

The steam turbine **107** includes a high pressure turbine **108** and a low pressure turbine **109**, and a power generator **110** is connected thereto. A moisture separation heater **111** is branched from the secondary cooling water pipe **106***a* and connected to the high pressure turbine **108** and the low pressure turbine **109**. The low pressure turbine **109** is connected to a condenser **112**. The condenser **112** is connected to the secondary cooling water pipe **106***b*. The secondary cooling water pipe **106***b* is connected to the steam generator **103** as described above, extending from the condenser **112** to the steam generator **103**, and is provided with a condensate pump **113**, a low-pressure feed water heater **114**, a deaerator **115**, a main feed water pump **116**, a high-pressure feed water heater **117**, and a main feed check valve **118**.

Accordingly, in the nuclear power plant, primary cooling water is heated by the pressurized water reactor **101** to become high-temperature and high-pressure primary cooling water, and is pressurized by the pressurizer **102** and fed to the steam generator **103** via the primary cooling water pipe **105**, with a constant pressure being maintained. In the steam generator **103**, heat exchange is performed between primary cooling water and secondary cooling water, so that secondary cooling water is evaporated to generate steam. Cooled primary cooling water after heat exchange is recovered on the primary cooling water pump **104** side via the primary cooling water pipe **105**, and returned to the pressurized water reactor **101**. Meanwhile, secondary cooling water that becomes steam by heat exchange is fed to the steam turbine **107**. The moisture separation heater **111** of the steam turbine **107** feeds overheated flue gas to the low pressure turbine **109**, after removing moisture from the flue gas from the high pressure turbine **108** and heating the flue gas so as to become an overheated state. The steam turbine **107** is driven by the steam of secondary cooling water, and the power thereof is transmitted to the power generator **110** to generate electricity. The steam used for driving the turbine is discharged to the condenser **112**. The condenser **112** performs heat exchange between cooling water (for example, sea water) taken by a pump **112***b* via an intake pipe **112***a* and steam discharged from the low pressure turbine **109**, and the steam is condensed and returned to low-pressure saturated liquid. Cooling water used for heat exchange is discharged from a discharge pipe **112***c*. Condensed saturated liquid becomes secondary cooling water, and is pumped to outside of the condenser **112** by the condensate pump **113** via the secondary cooling water pipe **106***b*. Secondary cooling water passing through the secondary cooling water pipe **106***b* is heated by, for example, low-pressure steam extracted from the low pressure turbine **109** in the low-pressure feed water heater **114**, and impurities such as dissolved oxygen and non-condensable gas (ammonia gas) are removed therefrom by the deaerator **115**. Thereafter, secondary cooling water is fed by the main feed water pump **116**, heated by high-pressure steam extracted from the high pressure turbine **108** in the high-pressure feed water heater **117**, for example, and returned to the steam generator **103**. A system that feeds secondary cooling water to the steam generator **103** is referred to as "main feed water system". In the main feed water system, the main feed water pump **116**, the main feed check valve **118**, and the like are controlled to maintain the water level of secondary cooling water in the steam generator **103**.

In this kind of nuclear power plant, an auxiliary feed water system is provided for maintaining the water level when the water level of secondary cooling water in the steam generator **103** cannot be maintained in the main feed water system. The auxiliary feed water system includes an auxiliary feed water pipe **120** connected to a subsequent stage of the main feed check valve **118** in the secondary cooling water pipe **106***b*, an auxiliary feed water pump **122** that feeds auxiliary cooling water (for example, saturated liquid condensed by the condenser **112**) stored in an auxiliary feed water pit **121** to the auxiliary feed water pipe **120**, and an auxiliary feedwater valve **123** that adjusts a flow rate of auxiliary cooling water passing through the auxiliary feed water pipe **120** and reaching the steam generator **103**. The auxiliary feed water system is set on a safe side such that the auxiliary feedwater valve **123** can be opened during a normal operation of the plant to feed auxiliary cooling water to the steam generator **103** by driving the auxiliary feed water pump **122**, and a check valve **124** is provided on a front stage of the auxiliary feedwater valve **123** in the auxiliary feed water pipe **120** for preventing secondary cooling water from flowing into the auxiliary feed water pipe **120** from the secondary cooling water pipe **106***b* during a normal operation of the plant. That is, in the auxiliary feed water system, when the water level of secondary cooling water in the steam generator **103** cannot be maintained in the main feed water system, the auxiliary feed water pump **122** is driven to feed auxiliary cooling water to the steam generator **103**.

In the present embodiment, an auxiliary feedwater valve control apparatus that controls the auxiliary feedwater valve **123** in the auxiliary feed water system is provided. FIG. **2** is a block diagram of the auxiliary feedwater valve control apparatus according to the present embodiment. The auxiliary feedwater valve control apparatus includes a water-level detection means **125** that detects a water level of secondary cooling water in the steam generator **103**. The auxiliary feedwater valve control apparatus also includes a control means **1** that controls the auxiliary feedwater valve **123** based on the water level detected by the water-level detection means **125**.

The control means **1** is constituted by a microcomputer or the like, and includes a storage means **2**, a water-level-deviation calculation means **3**, a valve-operation setting means **4**, and a valve drive means **5**.

The storage means **2** is constituted by a random access memory (RAM) or a read only memory (ROM), and programs and data are stored therein. The storage means **2** stores therein information of a preset target value (a target water level) of a water level to be maintained (target water level information). The storage means **2** also stores therein information specific to the auxiliary feedwater valve **123** (valve specific information). The valve specific information includes an opening/closing operation speed of the auxiliary feedwater valve **123**, the number of opening/closing operations per unit time of the auxiliary feedwater valve **123**, and a total operating time in the unit time of the auxiliary feedwater valve **123**. The opening/closing operation speed of the auxiliary feedwater valve **123** is measured in advance in the auxiliary feedwater valve **123** to be used, and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123** are mechanical restrictions according to a structure of the auxiliary feedwater valve **123** to be used. The storage means **2** also stores therein information of a time response of a water level corresponding

to the aperture of the auxiliary feedwater valve **123** (water-level time-response information). The water-level time-response information is acquired by a simulation in which the nuclear power plant described above is simulated (for example, see Japanese Patent Application Laid-open No. H6-231109 and Japanese Patent Application Laid-open No. H8-6483). The storage means **2** stores therein a non-minimum phase transfer function (see the following expression 1). In the expression 1, s denotes a Laplace operator, and a, b, and k are parameters for determining a time response of a water level.

$$k \cdot \frac{(b-s)}{s \cdot (s+a)} \tag{1}$$

The water-level-deviation calculation means **3** calculates a deviation between a target water level stored in the storage means **2** and a water level detected by the water-level detection means **125**.

The valve-operation setting means **4** includes a valve-aperture setting means **4***a*, a valve-driving-time setting means **4***b*, a valve-control-cycle setting means **4***c*, a one-cycle control-time setting means **4***d*, and an inverse-response-addition setting means **4***e*.

The valve-aperture setting means **4***a* sets an aperture of the auxiliary feedwater valve **123** corresponding to a deviation of a water level calculated by the water-level-deviation calculation means **3**. The aperture of the auxiliary feedwater valve **123** corresponds to a feed amount (a flow rate) of auxiliary cooling water passing through the auxiliary feedwater valve **123**, while setting that a feeding amount of auxiliary cooling water fed by the auxiliary feed water pump **122** is constant.

The valve-driving-time setting means **4***b* sets a driving time of the auxiliary feedwater valve **123** corresponding to the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a* based on the opening/closing operation speed of the auxiliary feedwater valve **123** stored in the storage means **2**. That is, the driving time of the auxiliary feedwater valve **123** is a time during which the auxiliary feedwater valve **123** is driven until the auxiliary feedwater valve **123** has the set aperture. Specifically, when a deviation between the target water level and the detected water level is large, the driving time of the auxiliary feedwater valve **123** becomes long, and when the deviation between the target water level and the detected water level is small, the driving time of the auxiliary feedwater valve **123** becomes short.

When the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** is defined, the valve-control-cycle setting means **4***c* sets a driving cycle of the auxiliary feedwater valve **123** corresponding to the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** stored in the storage means **2**. In this manner, the valve-control-cycle setting means **4***c* sets the driving cycle, that is, the number of times of driving of the auxiliary feedwater valve **123** until the water level reaches the target water level, under a restriction of the number of operations of the auxiliary feedwater valve **123**.

When the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123** are defined, the one-cycle control-time setting means **4***d* sets the driving cycle of the auxiliary feedwater valve **123** corresponding to the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** stored in the storage means **2**, and sets the longest driving time per driving cycle corresponding to the set driving cycle of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123** stored in the storage means **2**. In this manner, the one-cycle control-time setting means **4***d* sets the driving cycle, that is, the number of times of driving of the auxiliary feedwater valve **123** until the water level reaches the target water level, under a restriction of the number of operations of the auxiliary feedwater valve **123**, and sets the longest driving time per driving cycle, that is, the longest time during which the auxiliary feedwater valve **123** can be driven in one driving cycle, under a restriction of the total operating time in the unit time of the auxiliary feedwater valve **123**.

The inverse-response-addition setting means **4***e* adds an inverse response to the setting performed by the valve-aperture setting means **4***a*. FIG. **3** is a conceptual diagram of an inverse response. There is a temperature difference between secondary cooling water in the steam generator **103** and auxiliary cooling water fed from the auxiliary feedwater valve **123**, and secondary cooling water in the steam generator **103** has a comparatively high temperature. Therefore, as shown in FIG. **3**, when it is started to feed auxiliary cooling water to the steam generator **103** (a point A in FIG. **3**), secondary cooling water in the steam generator **103** is condensed due to the temperature difference, and such an inverse response occurs that the water level decreases once. In FIG. **3**, Xp denotes a maximum inverse response amount, Tp denotes a maximum inverse response time, Tr denotes an inverse response time, and V denotes a steady-water-level change speed.

The inverse-response-addition setting means **4***e* acquires the water-level time-response information and the non-minimum phase transfer function stored in the storage means **2**, determines a parameter in the non-minimum phase transfer function, which approximates a response to the water level from the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a* by the inverse response, based on the water-level time-response information, and sets the aperture of the auxiliary feedwater valve **123**, taking into consideration a gain margin and a phase margin of frequency characteristics of the non-minimum phase transfer function in which the parameter has been determined.

Approximation of a response to the water level from the aperture of the auxiliary feedwater valve **123** is performed based on the following expression 2, while designating that Laplace-transformed temporal variation of the auxiliary feedwater valve **123** is H(s), and Laplace-transformed temporal variation of the water level of the steam generator **103** is L(s).

$$L(s) = k \cdot \frac{(b-s)}{s \cdot (s+a)} \cdot H(s) \tag{2}$$

In the inverse response, Xp, Tp, and Tr increase with an increase in temperature, corresponding to the temperature of secondary cooling water in the steam generator **103**.

The inverse-response-addition setting means **4***e* respectively obtains the aperture of the auxiliary feedwater valve **123** corresponding to the deviation of the water level under different temperature conditions of secondary cooling water in the steam generator **103** included in the water-level time-response information, and a minimum value thereof is selected.

The valve drive means **5** outputs a signal for driving the auxiliary feedwater valve **123** corresponding to the setting by the valve-operation setting means **4**.

An operation of the auxiliary feedwater valve **123** performed by the control means **1** is explained below. FIG. **4** is a flowchart of an operation of the auxiliary feedwater valve control apparatus.

When the water level of secondary cooling water in the steam generator **103** cannot be maintained in the main feed water system, switching to the auxiliary feed water system is automatically performed. In this case, the water-level detection means **125** first detects a water level of secondary cooling water in the steam generator **103** (Step S**1**). The water-level-deviation calculation means **3** then calculates a deviation between the target water level and the detected water level (Step S**2**). The valve-operation setting means **4** then sets the aperture of the auxiliary feedwater valve **123** corresponding to the deviation of the water level (Step S**3**).

To take an addition of an inverse response into consideration, subsequent to Step S**3**, the inverse-response-addition setting means **4***e* sets the aperture of the auxiliary feedwater valve **123** according to the inverse response (Step S**4**).

To take into consideration an influence of the inverse response due to the temperature of secondary cooling water in the steam generator **103**, subsequent to Step S**4**, the inverse-response-addition setting means **4***e* selects the minimum amount of the aperture of the auxiliary feedwater valve **123** based on the different temperature conditions of secondary cooling water in the steam generator **103** (Step S**5**).

The valve-driving-time setting means **4***b* then sets the driving time of the auxiliary feedwater valve **123** corresponding to the aperture of the auxiliary feedwater valve **123**, based on the opening/closing operation speed of the auxiliary feedwater valve **123** (Step S**6**).

When the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** is defined, subsequent to Step S**6**, the valve-control-cycle setting means **4***c* sets the driving cycle of the auxiliary feedwater valve **123** corresponding to the driving time of the auxiliary feedwater valve **123** and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** (Step S**7**). For example, when the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* is relatively short (when the deviation between the target water level and the detected water level is relatively small), the water level reaches the target water level more quickly by extending the driving cycle (reducing the number of times of driving) of the auxiliary feedwater valve **123**. On the other hand, when the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* is relatively long (when the deviation between the target water level and the detected water level is relatively large), the water level reaches the target water level, while the water level is stabilized by finely adjusting the aperture, by shortening the driving cycle (increasing the number of times of driving) of the auxiliary feedwater valve **123**.

Furthermore, when the total operating time in the unit time of the auxiliary feedwater valve **123** is defined, subsequent to Step S**7**, the one-cycle control-time setting means **4***d* sets the longest driving time per driving cycle corresponding to the driving cycle of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123** (Step S**8**). For example, when the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* is relatively short (when the deviation between the target water level and the detected water level is relatively small), the water level reaches the target water level more quickly by extending the driving cycle (reducing the number of times of driving) of the auxiliary feedwater valve **123** and setting the longest driving time per driving cycle relatively long. On the other hand, for example, when the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* is relatively long (when the deviation between the target water level and the detected water level is relatively large), the water level reaches the target water level, while the water level is stabilized by finely adjusting the aperture, by shortening the driving cycle (increasing the number of times of driving) of the auxiliary feedwater valve **123** and setting the longest driving time per driving cycle relatively short.

Subsequent to Step S**8**, the valve drive means **5** outputs a signal for driving the auxiliary feedwater valve **123**, to finish the control.

If addition of the inverse response is not taken into consideration, subsequent to Step S**3**, the process proceeds to Step S**6**. If there is no influence of the temperature of secondary cooling water in the steam generator **103** in the inverse response, subsequent to Step S**4**, the process proceeds to Step S**6**. Furthermore, if the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123** are not defined, the valve drive means **5** outputs a signal for driving the auxiliary feedwater valve **123** subsequent to Step S**6**, to finish the control. Further, if the total operating time in the unit time of the auxiliary feedwater valve **123** is not defined, subsequent to Step S**7**, the valve drive means **5** outputs a signal for driving the auxiliary feedwater valve **123**, to finish the control.

In this control, by performing feedback control after the valve drive means **5** outputs a signal for driving the auxiliary feedwater valve **123**, water level control can be performed without causing any unsteadiness in the water level of the steam generator **103**, and therefore it is preferable.

As described above, the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment includes the water-level detection means **125** that detects the water level of secondary cooling water in the steam generator **103**, the water-level-deviation calculation means **3** that calculates a deviation between a preset target water level and a water level detected by the water-level detection means **125**, the valve-operation setting means **4** (the valve-aperture setting means **4***a*) that sets the aperture of the auxiliary feedwater valve **123** corresponding to the deviation of the water level, and the valve drive means **5** that outputs a signal for driving the auxiliary feedwater valve **123** corresponding to the setting by the valve-operation setting means **4**.

According to the auxiliary feedwater valve control apparatus of a steam generator, the auxiliary feedwater valve **123** is operated without corresponding to operations of an operator and water level control of secondary cooling water in the steam generator **103** can be automatically performed.

In the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment, the valve-operation setting means **4** includes the valve-driving-time setting means **4***b* that sets the driving time of the auxiliary feedwater valve **123** corresponding to the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a* or the inverse-response-addition setting means **4***e* based on an opening/closing operation speed of the auxiliary feedwater valve **123** measured in advance.

According to the auxiliary feedwater valve control apparatus of a steam generator, the driving time of the auxiliary feedwater valve **123** for realizing the set aperture of the aux-

iliary feedwater valve **123** is set based on the opening/closing operation speed of the auxiliary feedwater valve **123**. Accordingly, the aperture of the auxiliary feedwater valve **123** can be controlled corresponding to the performance of the auxiliary feedwater valve **123**.

In the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment, the number of opening/closing operations per unit time of the auxiliary feedwater valve **123** is defined. The valve-operation setting means **4** includes the valve-driving-time setting means **4***b* that sets the driving time of the auxiliary feedwater valve **123** corresponding to the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a* or the inverse-response-addition setting means **4***e* based on the opening/closing operation speed of the auxiliary feedwater valve **123** measured in advance, and the valve-control-cycle setting means **4***c* that sets the driving cycle of the auxiliary feedwater valve **123** corresponding to the set driving time of the auxiliary feedwater valve **123** and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123**.

According to the auxiliary feedwater valve control apparatus of a steam generator, the driving cycle of the auxiliary feedwater valve **123** is set corresponding to the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123**, thereby enabling to perform appropriate water level control until the water level reaches the target water level.

In the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment, the number of opening/closing operations per unit time and the total operating time in the unit time of the auxiliary feedwater valve **123** are defined. The valve-operation setting means **4** includes the valve-driving-time setting means **4***b* that sets the driving time of the auxiliary feedwater valve **123** corresponding to the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a* or the inverse-response-addition setting means **4***e* based on the opening/closing operation speed of the auxiliary feedwater valve **123** measured in advance, the valve-control-cycle setting means **4***c* that sets the driving cycle of the auxiliary feedwater valve **123** corresponding to the set driving time of the auxiliary feedwater valve **123** and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123**, and the one-cycle control-time setting means **4***d* that sets the longest driving time per driving cycle corresponding to the set driving cycle of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123**.

According to the auxiliary feedwater valve control apparatus of a steam generator, the driving cycle of the auxiliary feedwater valve **123** is set corresponding to the driving time of the auxiliary feedwater valve **123** set by the valve-driving-time setting means **4***b* and the number of opening/closing operations per unit time of the auxiliary feedwater valve **123**, and the longest driving time per driving cycle is set corresponding to the set driving cycle of the auxiliary feedwater valve **123** and the total operating time in the unit time of the auxiliary feedwater valve **123**, thereby enabling to perform appropriate water level control until the water level reaches the target water level.

In the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment, the valve-operation setting means **4** includes the inverse-response-addition setting means **4***e* that acquires the water-level time-response information corresponding to the aperture of the auxiliary feedwater valve **123** in advance, determines a parameter in the non-minimum phase transfer function, which approximates a response to the water level by the inverse response from the aperture of the auxiliary feedwater valve **123** set by the valve-aperture setting means **4***a*, based on the water-level time-response information, and sets the aperture of the auxiliary feedwater valve **123**, taking into consideration a gain margin and a phase margin of frequency characteristics of the non-minimum phase transfer function in which the parameter has been determined.

According to the auxiliary feedwater valve control apparatus of a steam generator, water level variation at the time of an inverse response can be suppressed by setting the aperture of the auxiliary feedwater valve **123** according to the inverse response.

In the auxiliary feedwater valve control apparatus of a steam generator according to the present embodiment, the inverse-response-addition setting means **4***e* of the valve-operation setting means **4** obtains the aperture of the auxiliary feedwater valve **123**, respectively, under different temperature conditions of secondary cooling water in the steam generator **103** included in the water-level time-response information, and selects a minimum value thereof.

When the temperature of secondary cooling water in the steam generator **103** is high, the temperature difference from auxiliary cooling water is large, and the maximum inverse response amount (Xp) increases, and when the feed amount of auxiliary cooling water increases, the maximum inverse response amount (Xp) further increases. Therefore, according to the auxiliary feedwater valve control apparatus of a steam generator, by setting the aperture of the auxiliary feedwater valve **123** according to the inverse response accompanied by the temperature condition to a minimum amount, water level variation at the inverse response time can be suppressed even if the temperature difference is large. Alternatively, a temperature detection means (not shown) that detects the temperature of secondary cooling water in the steam generator **103** can be provided, and the aperture of the auxiliary feedwater valve **123** can be set by matching the temperature detected by the temperature detection means with the temperature condition, thereby enabling to suppress water level variation at the time of an inverse response with any temperature.

REFERENCE SIGNS LIST

1 control means
2 storage means
3 water-level-deviation calculation means
4 valve-operation setting means
4*a* valve-aperture setting means
4*b* valve-driving-time setting means
4*c* valve-control-cycle setting means
4*d* one-cycle control-time setting means
4*e* inverse-response-addition setting means
5 valve drive means
103 steam generator
123 auxiliary feedwater valve
125 water-level detection means

The invention claimed is:

1. An auxiliary feed water system of a Pressurized Water Reactor comprising:

an auxiliary feed water pipe connected to a subsequent stage of a main feed check valve in a secondary cooling water pipe;

an auxiliary feed water pump that feeds auxiliary cooling water stored in an auxiliary feed water pit to the auxiliary feed water pipe; and

an auxiliary feedwater valve that adjusts a flow rate of the auxiliary cooling water passing through the auxiliary feed water pipe;

a water-level detection sensor that detects a water level of the secondary cooling water in the steam generator;

a microcomputer programmed to execute a water-level-deviation calculation program that calculates a deviation between a preset target water level and a water level detected by the water-level detection sensor;

the microcomputer programmed to execute a valve-operation setting program that sets an aperture of the auxiliary feedwater valve corresponding to a deviation of the water level; and

the microcomputer programmed to execute a valve drive program that outputs a signal for driving the auxiliary feedwater valve corresponding to setting by the valve-operation setting program, wherein

the valve-operation setting program acquires water-level time-response information corresponding to an aperture of the auxiliary feedwater valve in advance, determines a parameter in a non-minimum phase transfer function, which approximates a response to the water level by an inverse response from a set aperture of the auxiliary feedwater valve, based on the water-level time-response information, and sets the aperture of the auxiliary feedwater valve, taking into consideration a gain margin and a phase margin of frequency characteristics of the non-minimum phase transfer function in which the parameter has been determined.

2. The auxiliary feed water system according to claim **1**, wherein the valve-operation setting program sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance.

3. The auxiliary feed water system according to claim **1**, wherein

the number of opening/closing operations per unit time of the auxiliary feedwater valve is defined, and

the valve-operation setting program sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance, and sets a driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary feedwater valve.

4. The auxiliary feed water system according to claim **1**, wherein

the number of opening/closing operations per unit time and a total operating time in a unit time of the auxiliary feedwater valve are defined, and

the valve-operation setting program sets a driving time of the auxiliary feedwater valve corresponding to a set aperture of the auxiliary feedwater valve, based on an opening/closing operation speed of the auxiliary feedwater valve measured in advance, and sets a driving cycle of the auxiliary feedwater valve corresponding to the set driving time of the auxiliary feedwater valve and the number of opening/closing operations per unit time of the auxiliary feedwater valve, and sets a longest driving time per driving cycle corresponding to the set driving cycle of the auxiliary feedwater valve and the total operating time in the unit time of the auxiliary feedwater valve.

5. The auxiliary feed water system according to claim **1**, wherein the valve-operation setting program obtains an aperture of the auxiliary feedwater valve, respectively, under different temperature conditions of the secondary cooling water in the steam generator included in the water-level time-response information, and selects a minimum value thereof.

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